DETERMINING AVERAGE CYCLONIC ANGLE USING A 3-DIMENSIONAL PITOT PROBE

Purpose

This Air Quality Group procedure provides instruction for the measurement of average cyclonic angles (pitch and yaw angle) in LANL exhaust stacks, ducts, and vents using a 3-dimensional pitot probe. Cyclonic angle measurements are conducted to determine if a sampling location meets EPA Reference Method 1, Section 2.5 criteria for Method 2 flow measurements and/or sample collection.

Scope

This procedure applies to the measurement of average cyclonic flow angle in LANL exhaust stacks, ducts, and vents greater than 24 inches in diameter and where the measurement location is less than two duct diameters downstream or one-half duct diameter upstream of a flow disturbance.

In this procedure

This procedure addresses the following major topics:

Signatures

Prepared by: Victor Martinez, ESH-17	Date: 12/9/98
Approved by: Scott Miller, ESH-17 Rad-NESHAP Project Leader	Date: 12/9/98
Approved by: Terry Morgan, ESH-17 Quality Assurance Officer	Date: 12/9/98

Approved by:	Date:
_____ Doug Stavert, ESH-17 Group Leader	12/15/98

General information

Attachments

This procedure has the following attachments:

Number	Attachment Title	No. of pages
1	3-Dimensional Probe Calibration Data Form example	1
2	Directional Probe Setup Form example	1
3	Directional Probe Cyclonic Angle Measurement Form example	1
4	Directional Probe Cyclonic Angle Calculation Form example	1

History of revision

This table lists the revision history and effective dates of this procedure.

Revision	Date	Description Of Changes
0	12/16/98	New procedure

Who requires training to this procedure?

The following personnel require training before implementing this procedure:

- JCNNM technicians and staff members who perform or support exhaust stack, duct, or vent 3-D cyclonic angle measurements for ESH-17 Air Quality Group projects
- ESH-17 technicians and staff members who support exhaust stack, duct, or vent 3-D cyclonic angle measurements the ESH-17 Air Quality Group projects

Training method

The training methods for this procedure are:

- "classroom" and "OJT" for technicians and staff members *performing* 3-D cyclonic angle measurements and
- "self-study" for technicians and staff members *supporting* 3-D cyclonic angle measurements.

Annual retraining is required. Training is documented in accordance with the procedure for training (ESH-17-024).

General information, continued

Prerequisites

In addition to training to this procedure, the following training or surveillance programs are also required for technicians and staff members prior to performing flow measurements:

- Radiological Worker II Training (when required)
- PU access list (when required)
- ESH-5 full face respirator fitting and training program (when required)
- Site specific training as required for each facility
- ESH-17-024, "Personnel Training"
- ESH-17-026, "Deficiency Reporting and Correcting"

Recommended training

The following training is *recommended*, but not required:

- Tritium Safety
- Plutonium Safety
- Beryllium Health Hazards
- Hazard Communication Introduction

Hazard Control Plan

The Hazard Control Plans that document the hazards of work described in this procedure are:

ESH-17 work: HCP-ESH-17-Office Work, R0

JCNNM work: JCNNM is responsible for developing and maintaining hazard control plans for work performed by JCNNM workers.

HCP-ESH-17-Office Work is on file in the ESH-17 group office.

Definitions specific to this procedure

The following acronyms are used in this procedure:

AR - Administrative requirements

EDM - Electronic Digital Manometer

FMU - Facility Management Unit

JCNNM - Johnson Controls Northern New Mexico

LIR - Laboratory Implementation Requirement

NIST - National Institute of Standards and Technology

General information, continued

References

The following documents are referenced in this procedure:

National Codes And Standards

- 40 CFR 61 Subpart H, “National Emission Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities”
- Method 1: EPA 40 CFR 60 Appendix A Test Method, “Sample And Velocity Traverses For Stationary Sources”
- Method 1A: EPA 40 CFR 60 Appendix A Test Method, “Sample And Velocity Traverses For Stationary Sources With Small Stacks Or Ducts”
- Method 2: EPA 40 CFR 60 Appendix A Test Method, “Determination Of Stack Gas Velocity And Volumetric Flow Rate (Type S Pitot Tube)”
- Method 2C: EPA 40 CFR 60 Appendix A Test Method, “Determination Of Stack Gas Velocity And Volumetric Flow Rate In Small Stacks Or Ducts (Standard Pitot Tube)”
- Method 2F: EPA 40 CFR 60 Appendix A Test Method, “Determination of Stack Gas Velocity and Volumetric Flow Rate Using a Directional Pitot Tube”, **Draft**

Los Alamos National Laboratory Requirements

- LIR 230-03-01, “Facility Management Work Control”
- LIR 402-10-01, “Hazard Analysis and Control for Facility Work”
- LIR 402-701-01.2, “Radiological Access Control”
- LIR 402-704-01.2, “Contamination Control”
- LIR 402-710-01.2, “Radiological Personal Protective Equipment”
- LIR 402-719-01.1, “Workplace Monitoring”
- LIR 402-720-01.1, “Work Planning"

ESH-17 Procedures

- ESH-17-024, “Personnel Training”
- ESH-17-026, “Deficiency Reporting and Correcting”
- ESH-17-127, “Determination of Stack Gas Velocity and Flow Rate in Exhaust Stacks, Ducts, and Vents”
- ESH-17-128, “Determination of the Average Cyclonic Flow Angle in Exhaust Stacks, Ducts, and Vents”

Manufacturer’s Literature

- Refer to the manufacturer’s literature for each instrument

Note

Actions specified within this procedure, unless preceded with "should" or "may", are to be considered mandatory guidance (i.e., "shall").

Work control

General

JCNNM coordinates all work with the appropriate facility management unit in accordance with LIR 230-03-01, "Facility Management Work Control."

Work order

The **ESH-17 Rad-NESHAP Project Leader** will issue and annually fund a work order to capture costs for the exhaust stack flow measurement program. This includes special flow measurements such as cyclonic angle determinations. All work will be reviewed and performed under appropriate work tickets.

Work tickets

All 3-D cyclonic angle measurements will be performed and charged to separate work tickets. The **ESH-17 Rad-NESHAP Project Leader** will submit a work ticket for each measurement (or group of measurements within one building and FMU) to the appropriate FMU for review and processing.

Facility check-in and check-out

Special check-in and check-out procedures must be followed for working in certain facilities. The appropriate **work crew foreman** ensures that all check-in and check-out procedures are followed and that the work crew is briefed prior to being dispatched to perform the work.

Measurement frequency

Three-dimensional cyclonic angle measurements are performed at a site to determine whether the site meets the criteria specified in EPA Reference Method 1, Section 2.5 for the use of Method 2 flow measurements and/or sample collection. These measurements are generally performed only one time at a site.

Safety and hazard analysis

ES&H hazard screening

As required by LIR 230-03-01, "Facility Management Work Control," perform an ES&H hazard screening in accordance with LIR 402-10-01, "Hazard Analysis and Control for Facility Work."

Potential hazards to consider

The following types of hazards may be present during cyclonic angle measurements and must be addressed during the hazard analysis:

- Radiation
- chemical emissions
- rotating machinery
- heights (e.g., roofs, scaffolding, bucket truck, etc.)
- weather (e.g., lightning, snow, ice, etc.)
- noise
- heat exposure
- falling objects
- compressed air

Radiological/ Chemical hazards

Before scheduling access to roof tops or the opening of stack measurement ports, determine if planned laboratory processes could be producing unusual radiological hazards or chemical emissions during the time maintenance personnel plan to be working with the stacks.

Potentially contaminated equipment

Obtain clearance from the site radiological control technician in accordance with facility requirements and relevant sections of LIR 402-701-01.2, LIR 402-704-01.2, LIR 402-710-01.2, LIR 402-719-01.1, and LIR 402-720-01.1 for equipment used to measure cyclonic angles in potentially radioactive stacks. If radioactive contamination is detected, the equipment must be decontaminated by trained and qualified personnel before being removed from the site.

Personal protection equipment

Wear safety shoes and safety glasses while performing all cyclonic angle measurements. The following *additional* personal protective equipment may be required:

- hard hat
- hearing protection
- anti-contamination clothing including rubber gloves
- respirator

Permits

Ensure all permits (e.g., radiation work permits) are issued before work is released to the crafts.

Equipment specifications

Acceptable equipment	Specifications for equipment to be used to perform this procedure are given below. Other equipment meeting these specifications may be acceptable. **ESH-17 must obtain approval from EPA for substitute equipment not specified below.**
Directional probe	Use a three-dimensional directional probe that is capable of measuring both the pitch and yaw angles of gas flows, such as ESH-17's United Sensor Type DA Probe. Ensure an identification number is assigned to the directional probe and be permanently marked or engraved on the body of the probe.
Yaw angle measurement device	When the directional probe is rotated from a reference position, use a device to measure the yaw angle to within ± 1°. A protractor with an appropriate indicator is an acceptable device.
Differential pressure gauges	Use differential pressure gauges that meet the criteria of 40 CFR 60, Appendix A, Method 2, Section 2.2. ESH-17's Environmental Supply Company Model C-3D-MAG Three Dimensional Pitot Control monitoring console is an acceptable system.
Special tools	The following special tools must be available and may be needed to perform this procedure: • pitot tube level • pitot tube square • pitot tube mounting bracket and hardware • pitot tube traversing station

Equipment calibration

Equipment calibration requirements

All equipment used to perform this procedure must meet the calibration requirements described below.

Differential pressure gauges

Ensure differential pressure gauge(s) have calibration traceable to the National Institute of Standards and Technology (NIST) standards. Differential pressure gauge(s) must be re-calibrated at least annually against a NIST traceable reference meter. Readings must agree to within ± 2 percent. If the gauge reads both positive and negative differential pressures, then both the positive and negative scales must be calibrated at a minimum of three points, as specified in EPA Method 2, Section 2.2.

Calibration pitot tube

Ensure the standard pitot tube (used for calibrating the directional probe) has a known coefficient obtained either directly from NIST or by calibration against another standard pitot tube with an NBS-traceable coefficient.

Equipment calibration, continued

3-dimensional pitot probe

The instructions below apply to calibrating ESH-17's United Sensor Type DAT-375, 3-dimensional pitot probe. This probe must be re-calibrated at least annually and whenever visible damage to the sensing head is detected.

Steps to perform calibration

To calibrate the United Sensor Type DAT-375 3-dimensional pitot probe, perform the following steps:

Step	Action
Prepare calibration flow system	
1	Confine the flowing gas stream to a duct of definite cross-sectional area, either circular or rectangular. **Note:** For circular cross-sections, the minimum duct diameter must be 12 inches; for rectangular cross-sections, the width (shorter side) must be at least 10 inches. The cross-sectional area of the calibration duct must be constant over a distance of 10 or more duct diameters. For a rectangular cross-section, use an equivalent diameter, calculated from the following equation, to determine the number of duct diameters: $D_e = 2LW/(L+W)$ where: D_e = Equivalent diameter L = Length W = Width
2	To ensure the presence of stable, fully developed, axial flow patterns at the calibration site or "test section," locate the site at least eight diameters downstream and two diameters upstream from the nearest disturbances. **Note:** The eight- and two-diameter criteria, as well as the constancy of the cross-sectional area, are not absolute; other test section locations may be used (subject to approval of the EPA Administrator), provided that the flow at the test site is stable and demonstrably parallel to the duct axis. The use of straightening vanes or screens is highly recommended to develop axial flow. The flow system must have the capacity to generate two test-section velocities: one between 20 and 40 (feet per second) fps and one between 40 and 60 fps. The velocities must be constant with time to guarantee steady flow during calibration.

Equipment calibration, continued

Step	Action
3	Cut two entry ports in the test section. **Note:** The axis through the entry ports must be perpendicular to each other and intersect in the centroid of the test section. The ports should be elongated slots parallel to the axis of the test section and of sufficient length to allow measurement of pitch angles while maintaining the pitot head position at the test-section centroid. To facilitate alignment of the directional probe during calibration, the test section should be constructed of plexiglass or some other transparent material. All calibration measurements should be made at the same point in the test section, preferably at the centroid of the test section.
4	To ensure that the gas flow is parallel to the central axis of the test section, measure the yaw angle at the centroid of the test section from two test ports located 90° apart. **Note:** The yaw angle measured in each port must be within ± 2º of 0º. If necessary, install straightening vanes to meet this criterion.
Pitch angle calibration	
5	Perform a calibration traverse according to the manufacturer's recommended protocol in 5° increments for angles from -60° to +60° at two velocities; one velocity in each of the two ranges specified in Step 2 above.
6	Average the pressure ratio values obtained for each angle in the two flow ranges.
7	Plot a calibration curve with the average values of the pressure ratio (or other suitable measurement factor as recommended by the manufacturer) versus the pitch angle.
8	Draw a smooth line through the data points.
9	Plot the data values for each traverse point.
10	Determine the differences between the measured data values and the angle from the calibration curve at the same pressure ratio. **Note:** The difference at each comparison must be within 2° for angles between 0° and 40° and within 3° for angles between 40° and 60°.
Yaw angle calibration	
11	Mark the three-dimensional probe to allow the yaw position of the probe to be determined. **Note:** This is usually a line extending the length of the probe and aligned with the impact opening.
12	To determine the accuracy of measurements of the yaw angle, calibrate only the zero or null position as instructed in the next steps.
13	Place the directional probe in the test section and rotate the probe until the zero position is found.

Equipment calibration, continued

Step	Action
14	Using a protractor or other angle measuring device, measure the angle indicated by the yaw angle indicator on the three-dimensional probe. **Note:** This should be within 2° of 0°.
15	Repeat this measurement for any other points along the length of the pitot where yaw angle measurements could be read in order to account for variations in the pitot markings used to indicate pitot head positions.
16	This calibration curve should apply to a velocity range of about 20 fps to 100 fps for pitch angles between ± 40º. If measurements are conducted below 20 fps, generate a separate calibration curve at 10 fps or as close as possible to the actual measurement level. **Note:** If the above specifications cannot be met, consider limiting the applicability of the calibration curve to a finite velocity range over which measurements can be obtained within the specifications.

Measuring cyclonic flow angle

Background

Before measuring the volumetric flow rate in certain designated exhaust stacks, ducts, and vents (in accordance with 40 CFR 60, Appendix A, Test Method 2), LANL must first determine whether flow conditions at the sample location meet certain specifications, one of which is that the cyclonic angle is below an acceptable level. In most stationary sources, the direction of the stack gas flow is essentially parallel to the stack walls. However, cyclonic flow may exist (1) after such devices as cyclones and inertial demisters following venturi scrubbers, or (2) in stacks having tangential inlets or other duct configurations that tend to induce swirling. When the stack, duct, or vent has an equivalent diameter larger than 24 inches and the sampling location is less than two diameters downstream or one-half diameter upstream of the nearest flow disturbance, a three-dimensional probe is required for determining cyclonic angle, as prescribed by Method 1, Section 2.5.

Exhaust stack measurement location (i.e., profile location)

The **ESH-17 Rad-NESHAP Project engineer** specifies the location on the exhaust stack to perform 3-D cyclonic angle measurements and the number of traverses, the number of measurement points and their spacing along each traverse. In no case shall less than 40 measurement points be used.

The measurement location, the number of traverses, and the number of measurement points along each traverse defines the profile. The **ESH-17 Rad-NESHAP Project engineer** identifies each profile on a stack with a unique number.

Field measurement forms

Record all field measurement data on Field Measurement Forms (see Attachments 2 and 3). Record all entries in ink. Correct any errors by striking through the erroneous entry with a single line and annotating the correct information in an empty space directly adjacent to the error. Initial and date the correction. Individuals performing the measurements and the calculations must sign and date final field measurement forms.

Field conditions

Perform cyclonic angle measurements only when an exhaust stack, duct, or vent is exhausting ambient air from a laboratory or facility.

Measuring cyclonic flow angle, continued

Steps to perform measurements

To measure cyclonic angle in a stack, duct, or vent, perform the following steps:

Step	Action
Determining the location for performing measurements	
1	Obtain the location on the stack or duct for performing the measurement from ESH-17. The location is given by the Profile Measurement Number.
Preparing measurement input forms	
2	Record the TA, building, exhaust stack (ES) ID Number and exhaust fan(s) numbers on the top of the Directional Probe Setup Form (Attachment 2). The ES ID Number is the eight digit number, TA-BLDG-ES, with leading zeros. Also record the profile number, the fan configuration number, and the measurement date.
Preparing equipment	
3	Select the correct directional probe(s) for the stack(s) to be analyzed. Inspect the sensing head of the probe(s) to be used and verify it is not damaged. Each directional probe should be long enough to reach all traverse points through the cross-section of the stack(s).
4	Calculate the distances from the hole in the stack wall to each traverse point. If the stack is equipped with port nipples, insure this distance is taken into account when calculating the traverse point.
5	Measuring from the impact hole (P1) of the directional probe, mark the calculated distances on the probe with a felt-tipped pen so that the probe can be correctly positioned from the hole in the stack wall to each traverse point. Have a second qualified stack measurement craftsman independently verify the markings.
6	Verify that the directional probe and pressure measurement console calibration certifications have not expired. Record, in section 1 of the Directional Probe Setup Form (Attachment 2), the type, identifying information, and calibration expiration date of the directional probe and pressure measurement console to be used.
7	Check the box in section 1 of the Directional Probe Setup Form indicating that the traverse spacing has been marked on the directional probe and that the directional probe has been inspected.

Measuring cyclonic flow angle, continued

Step	Action
Verifying exhaust system is exhausting ambient air and inspecting system	
8	Check with Facility Management before starting cyclonic angle measurements to verify that the stack is not exhausting radioactive or other hazardous process exhaust. Perform cyclonic angle measurements only when an exhaust stack, duct, or vent is exhausting ambient air from a laboratory or facility.
9	Before measuring the cyclonic angles, inspect the exhaust system, i.e. fan(s), dampers, etc. Record, in section 2 of the of the Directional Probe Setup Form, any unusual conditions or variations observed in the configuration of the exhaust system during the inspection. If the conditions observed may affect the accuracy or representativeness of the cyclonic angle measurement (e.g., blocked filter), **do not** perform the measurement until the unusual condition has been resolved. Report these findings to the Facility Management Unit before leaving the work area. **If conditions present may present a hazard, DO NOT perform the cyclonic angle measurements. Report the conditions to the FMU and reschedule the cyclonic measurements after the hazard has been mitigated.**
Setting up and adjusting equipment	
10	Install the appropriate mounting bracket and traversing station, if necessary, on the exhaust stack. Verify that the traversing station is level and appropriately supported.
11	Connect the pressure measurement console to the directional probe in the manner described in the manufacturer's instructions. ESH-17's United Sensor Type DA Probe is connected to the Environmental Supply Company Model C-3D-MAG Three Dimensional Pitot Control monitoring console by firmly inserting the male portion of each quick-connect fitting into the corresponding female portion. Connect the other end of the surgical tubing to the corresponding fitting on the probe connection head.
12	Connect the pressure measurement console to a standard 110V electrical power supply.
13	Purge all connection lines with the installed pump in the measurement console by setting all of the read/purge valves (lower right corner of the pressure measurement console) to the "purge" position and turning the pump switch (lower left corner of the console) to the "on" position. Purge for 30 seconds, then turn off the pump. Return valves to the "read" position.
14	Record a check mark in the appropriate box in section 3 of the Directional Probe Setup Form.

Measuring cyclonic flow angle, continued

Step	Action
15	Verify all gauges have a zero reading. If necessary, zero the pressure measurement system. ESH-17's Environmental Supply Company Model C-3D-MAG Three Dimensional Pitot Control monitoring console is zeroed by adjusting the zeroing screws on the face of each magnehelic gauge. Because the pressure measurement system zero may drift due to vibrations and temperature changes, make periodic checks during the traverse.
16	Record a check mark in the appropriate box in section 3 of the Directional Probe Setup Form.
17	Go to the *Leak Checking The 3-Dimensional Pitot Probe And Pressure Measurement Console* chapter of this procedure and perform a pre-test leak check of the probe and pressure measurement system. **Do Not Pressurize The System By Mouth!** If the system does not pass the leak test, correct the problem before making cyclonic angle measurements. Return to Step 18 after performing the leak check.
18	Record the results of the leak check in section 4 of the Directional Probe Setup Form (Attachment 2).
Performing traverse readings	
19	Insert the directional probe into the exhaust stack to the first traverse point.
20	Verify there is an adequate seal between the stack wall and the directional probe.
21	Verify with a level and square that the directional probe is parallel to the cross-sectional plane of the stack and perpendicular to the stack wall. Verify that the impact opening (P_1) is parallel to the stack axis. By placing a level on the probe connection head. **IMPORTANT: The directional probe MUST be parallel to the cross-sectional plane of the stack and MUST be perpendicular to the stack wall, and the impact opening (P_1) MUST be parallel to the stack axis.** Verify the installed angle finder reads 0° at this location. Adjust if necessary. The directional probe is now in the 0° reference position. Measure all angles relative to this reference position.
22	Record the time of the first reading in section 5 of the Directional Probe Setup Form.

Measuring cyclonic flow angle, continued

Step	Action
23	Rotate the directional probe about its axis until the yaw angle differential pressure gauge on the pressure measurement console reads zero.
24	Using the installed protractor, carefully determine the value of the rotation angle to the nearest degree. Record this value in the yaw angle column of the Directional Probe Cyclonic Angle Measurement Form (Attachment 3).
25	Without moving the directional probe, read the velocity pressure and pitch pressure from the pressure measurement console and record it in the appropriate columns of the Directional Probe Cyclonic Angle Measurement Form (Attachment 3). **Note:** It may take about 3 minutes for readings to stabilize.
26	If the pitch pressure gauges indicate a negative pressure, reverse the position of the sense-reversal switch (located below those gauges on the pressure measurement console) prior to reading and recording the pressure. When recording the pitch pressure, also record the position of the sense-reversal switch ("+" or "-").
27	If the probe shows indications of plugging (e.g., erratic results or sluggish responses), purge the probe and connection lines (see Step 28 below) and repeat the measurement.
28	Purge the probe and all connection lines for about 30 seconds by turning the read/purge valves on the pressure measurement console (lower right of the console) to the "purge" setting and turning on the pump (switch is in the lower left of the console face).
29	Repeat steps 23 through 28 at the traverse points specified by EPA Reference Method 1 or 1A (provided by ESH-17). Remove the bracket and traversing station and reinsert the hole plug after each traverse has been completed.
30	Move the bracket and traversing station to the next sampling location and repeat steps 19 through 28.
31	Record the time of the last reading in section 5 of the Directional Probe Setup Form (Attachment 2).
32	Go to the *Leak Checking The 3-Dimensional Pitot Probe And Pressure Measurement Console* chapter of this procedure and perform a post-test leak check of the probe and pressure measurement system. **Do Not Pressurize The Tube By Mouth!** If the system does not pass the leak test, void the measurement. Correct the problem and repeat the cyclonic angle measurements. Return to Step 33 after performing the leak check.
33	Record the results of the post-test leak check in section 6 of the Directional Probe Setup Form (Attachment 2).

Measuring cyclonic flow angle, continued

Step	Action
34	Record any condition(s) that may affect the accuracy or the validity of the measurement data in section 7 of the Directional Probe Setup Form.
35	Plug the last hole. Mark the box in section 8 of the Directional Probe Setup Form (Attachment 2).
36	Inspect the work site to be sure all equipment and tools have been collected.
Differential pressure meter	
37	If differential pressure gauges other than inclined manometers are used (e.g., magnehelic gauges), check their calibration as described below after each test series. Compare Δp readings of the gauge with those of an oil-gauge manometer at a minimum of three points, approximately representing the range of Δp values in the stack. If, at each point, the values of Δp as read by the differential pressure gauge and gauge-oil manometer agree to within 5%, the differential pressure gauge is in calibration. Otherwise, void the test series or, with approval from the EPA Administrator, adjust the measured Δp values and final results. Record the results of this calibration check in section 9 on the Directional Probe Setup Form (Attachment 2).
Completing and submitting forms	
38	Complete, sign, and forward the Directional Probe Setup Form (Attachment 2) and the Directional Probe Cyclonic Angle Measurement Form (Attachment 3) to the JCNNM facility engineer for the calculation and/or verification of the cyclonic angles. See the *Records resulting from this procedure* section of this procedure.

Leak checking the 3-dimensional pitot probe and pressure measurement console

Overview

The instructions below are used to leak check the United Sensor Type DAT-375 3-dimensional pitot probe and Environmental Supply Company Type C-3D-MAG pressure measurement console.

Steps to perform leak check

To perform a leak check of the United Sensor Type DAT-375 3-dimensional pitot probe and Environmental Supply Company Type C-3D-MAG pressure measurement console, perform the following steps:

Step	Action
Connect equipment	
1	Connect the 3-dimensional probe to the pressure measurement console and following the manufacturer's instructions. Connect the pressure measurement console to a 110-volt electrical power supply.
Initial settings	
2	Set all of the shutoff valves (lower right corner of the pressure measurement console) to the "purge" position.
Conduct leak check	
3	Set the shutoff valve labeled number 1 to the "read" position. Apply pressure to the sensing head of the 3-D pitot probe until the high range velocity pressure magnehelic gauge (upper right gauge on pressure measurement console) reads between 3 and 5 inches of water. Quickly seal the pressurization line to the sensing head of the 3-D pitot probe with a small diameter surgical tubing. The reading on the high range velocity pressure magnehelic gauge should remain constant for 15 seconds.
4	If the pressure drops, disconnect the 3-D probe from the pressure measurement console and identify whether the leak is in the probe, connecting lines, or console before continuing this leak check procedure. If the pressure remains constant, release the small diameter tubing and return the valve labeled number 1 to the "purge" position and continue with Step 5.
5	Set the shutoff valve labeled number 2 to the "read" position. Apply suction, with a surgical syringe, to the sensing head of the 3-D pitot probe until the high range velocity pressure magnehelic gauge (upper right gauge on pressure measurement console) reads between 3 and 5 inches of water. Quickly, seal the pressurization line to the sensing head of the 3-D pitot probe with a small diameter surgical tubing. The reading on the high range velocity pressure magnehelic gauge should remain constant for 15 seconds.

Leak checking the 3-dimensional pitot probe and pressure measurement console, continued

Step	Action
6	If the pressure remains constant, return the valve labeled number 2 to the "purge" position and continue with Step 7. If the pressure drops, determine the cause, correct the problem, and repeat Step 5.
7	Set the shutoff valves labeled number 3 and number 1 to the "read" position. Apply pressure to the sensing head of the 3-D pitot probe until the upper right magnehelic gauge reads +3.0 inches of water, then seal the pressurization line to the sensing head of the 3-D pitot probe as described in step 3. The reading on the upper right magnehelic gauge should remain constant for 15 seconds.
8	If the pressure remains constant, return the valve labeled number 3 to the "purge" position and continue with Step 9. If the pressure drops, determine the cause, correct the problem, and repeat Step 7.
9	Set the shutoff valve labeled number 4 to the "read" position. Apply pressure to the sensing head of the 3-D pitot probe and observe the upper right magnehelic gauge; if this gauges indicates a negative pressure, reverse the position of the switch located just below the pitch angle gauges. Once the magnehelic gauge reads 3 inches of water, seal the pressurization line to the sensing head of the 3-D pitot probe as described in step 3. The reading on the upper right magnehelic gauge should remain constant for 15 seconds.
10	If the pressure remains constant, return the valve labeled number 4 to the "purge" position and continue with Step 11. If the pressure drops, determine the cause, correct the problem, and repeat Step 9.
11	Reverse the position of the switch below the pitch angle gauges. Repeat Step 9, using the shutoff valve labeled number 5 instead of number 4. If the pressure remains constant, the system passes the leak check. If the pressure drops, determine the cause, correct the problem and repeat Step 9.
12	Return to the appropriate step in the *Measuring Cyclonic Flow Angle* chapter of this procedure as indicated below:

If this check was a…	then return to…
pre-test leak check	Step 18.
post-test leak check	Step 33.

Performing calculations

Performing calculations

Perform calculations in accordance with the instructions below. Retain at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculation. Record the results on the Directional Probe Cyclonic Angle Calculation Form (Attachment 4).

Determine pitch angles from calibration curves

For each measurement point, calculate the value $(P_4 – P_5)/(P_1 – P_2)$ and record the value on the appropriate line of the Directional Probe Cyclonic Flow Angle Measurement Form (Attachment 3).

Using the calibration curves for the specific probe, determine the pitch angle at each measurement point from the value $(P_4 – P_5)/(P_1 – P_2)$, and record the pitch angle on the appropriate line of the Directional Probe Cyclonic Angle Measurement Form.

Calculate resultant angle at each point

For each measurement point, calculate the resultant angle as follows:

$$R_i = \text{arc cosine } [(\cos (Y_i))(\cos (P_i))]$$

where: R_i = resultant angle at measurement point "i"
Y_i = yaw angle at measurement point "i"
P_i = pitch angle at measurement point "i"

Record the resultant angle in the appropriate space of the Directional Probe Cyclonic Angle Measurement Form.

Calculate average resultant for measurements

For each set of measurements, calculate the average resultant angle as follows:

$$R_{AVG} = (\sum R_i) / n$$

where:

R_{AVG} = average resultant angle for a set of measurements
n = number of measurements in the set

Performing calculations, continued

Calculate standard deviation

For each set of measurements, calculate the standard deviation of the average resultant angle as follows:

$$S_d = \{[\sum(R_i - R_{AVG})^2]/(n-1)\}^{1/2}$$

where: S_d = standard deviation of the average resultant angle

Acceptance criteria

If the average resultant angle (R_{AVG}) is less than or equal to 20° and the standard deviation of the average resultant angle (S_d) is less than or equal to 10°, then overall flow conditions in the exhaust stack is acceptable for EPA Reference Method 1 and Reference Method 2 flow measurements and/or sampling location.

Submitting flow measurement reports to ESH-17

Provide ESH-17 with the original and one copy of the signed cyclonic angle measurement report **within seven days** of performing cyclonic angle measurements. Include the original and one copy of the following completed forms:

- 3-Dimensional Probe Calibration Data Form (Attachment 1) (if calibration is performed)
- Directional Probe Setup Form (Attachment 2)
- Directional Probe Cyclonic Angle Measurement Form (Attachment 3)
- Directional Probe Cyclonic Angle Calculation Form (Attachment 4)

Records resulting from this procedure

Work order documents maintained by JCNNM

Work records must be maintained by JCNNM. Records to be filed and maintained in shop files for a minimum of two years include, as a minimum, copies of the following documentation:

- program work orders
- work tickets
- hazard analysis

Records maintained by ESH-17

Submit the original signed cyclonic angle measurement report and the original copy of the following forms to the records coordinator **within seven days** of receiving these documents from JCNNM:

- 3-Dimensional Probe Calibration Data Form (Attachment 1) (if calibration is performed)
- Directional Probe Setup Form (Attachment 2)
- Directional Probe Cyclonic Angle Measurement Form (Attachment 3)
- Directional Probe Cyclonic Angle Calculation Form (Attachment 4)

ESH-17, Air Quality

3-Dimensional Probe Calibration Data Form

 This form is from ESH-17-129

Probe I.D. _____ Length _____ Serial No. _____

Date of Calibration _____ Personnel _____

Standard Pitot: C_{PS} _____

Yaw Angle Test

Percent of total probe length	20	40	60	80	100
Indicated yaw angle					

$F_1 = (P_4 - P_5)/(P_1 - P_2)$ $F_2 = C_P [(P_t - P_s)/(P_1 - P_2)]$

Pitch Angle (degrees)	$P_1 - P_2$ (in. H_2O)	$P_4 - P_5$ ± (in. H_2O)	$P_t - P_s$ (in. H_2O)	F_1	F_2	Velocity (fps)
-60						
-55						
-50						
-45						
-40						
-35						
-30						
-25						
-20						
-15						
-10						
-5						
0						
5						
10						
15						
20						
25						
30						
35						
40						
45						
50						
55						
60						

Calibration Performed By:

_____	_____	_____	_____/_____/_____
Name	Signature	Z-Number	Date

ESH-17, Air Quality

Directional Probe Setup Form

 This form is from ESH-17-129

TA/Building/ES _____-_____-_____ FE(s) _____

Profile Measurement Number _____ Fan Exhaust Configuration _____

Measurement Date _____/_____/_____

1. Equipment used and calibration

Pressure Measurement System Type _Environmental Supply Co. Model C-3D-MAG Console
Serial Number _ESH-17-001_____ Calibration Expiration ____/____/____

Directional Probe Type _United Sensor Type DAT-375 Three-Dimensional Pitot Probe
Serial Number __C-3386___ Calibration Expiration ____/____/____

☐ Traverse spacing pre-marked on directional probe / directional probe inspected

2. Location inspection

Location Comments: _____

3. Equipment setup

☐ Install mounting bracket, traversing station and support; ☐ Not Necessary

☐ Connect directional probe to pressure measurement system and 110V power; purge all lines

☐ Zero the pressure measurement system

4. Pre-measurement leak test

☐ successful ☐ successful after correcting following problem _____

5. Perform traverse readings (record yaw angle, velocity pressure, and pitch pressure [incl. "+" or "-"]) on Directional Probe Cyclonic Angle Measurement Form

Run Start Time: _____ Run Complete Time: _____

6. Post measurement leak test

☐ successful ☐ measurement voided

7. Condition(s) that might affect measurements

_____

8. Holes covered

☐ Complete

9. Post Measurement Verifications

☐ Differential pressure meter verification passed (within 5%) ☐ Meter verification not required.

Test Number	Test Velocity (fpm)	Differential Pressure (inches wg)		
		Differential Pressure Meter	Reference Inclined Manometer	% Difference
1				
2				
3				

Measurements Performed By:

M	A/R	Name	Signature	Z-Number	Date

Reviewed by:

_____
Date:

_____

ESH-17, Air Quality

Directional Probe Cyclonic Angle Measurement Form

Page _____ of _____ This form is from ESH-17-129

TA/Building/ES _____-_____-_____ Measurement Date _____/_____/_____

Measurement Traverse _____

Point	Spacing (nearest 1/8 in)	Yaw Angle (degrees)	Velocity Pressure ($P_1 - P_2$) (in. H_2O)	Pitch Pressure ($P_4 - P_5$) (in. H_2O)		$\frac{(P_4 - P_5)}{(P_1 - P_2)}$	Pitch Angle (degrees)
				(+/-)			

Cyclonic angle measurements were performed in accordance with ESH-17-129

_____ _____ _____ _____/_____/_____

Name Signature Z-Number Date

ESH-17, Air Quality

Directional Probe Cyclonic Angle Calculation Form

Page _____ of _____ This form is from ESH-17-129

TA/Building/ES _____-_____-_____ Measurement Date _____/_____/_____

Traverse Point	Resultant Angle (R_i) R_i=arc cos[(cos (Y_i)(cos (P_{ij})]	(R_i – R_{AVE})^2	Traverse Point	Resultant Angle (R_i) R_i=arc cos[(cos (Y_i))(cos (P_i))]	(R_i – R_{AVE})^2

Average Resultant Angle, R_{AVE} (n= 40 Pts) R_{AVE}= (ΣR_i)/n	$\Sigma(R_i – R_{AVE})^2$; (40 Pts)	Standard Deviation, S_d ; (n= 40 Pts) S_d = {[$\Sigma(R_i – R_{AVE})^2$]/(n-1)}$^{1/2}$

Calculations were performed in accordance with ESH-17-129

_____	_____	_____	_____/_____/_____
Name	Signature	Z-Number	Date